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A Spectorophotometric and Spectroscopic Study of Phi Persei

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A SPECTROPHOTOMETRIC AND SPECTROSCOPIC STUDY OF PHI PERSEI

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The great importance of intensity studies in stellar spectra has long been recognized and as such has been the subject of many investigations. Most of the early studies have been on the intensity distribution of the continuous spectrum. The more recent investigations have been confined to special regions of the continuous spectrum as well as on selected spectral lines. Various methods have been used for such intensity studies.

The purpose of this investigation is to determine a standard calibration curve for the reduction of photograms made with the Moll self-registering microphotometer, and to make an intensive study of the hydrogen lines observed in the spectrum of Phi Persei. The spectrum of Phi Persei is of class Bope. The outstanding features in this spectrum are the variable hydrogen lines. They appear as very broad absorption with a narrower emission superimposed. This, however, has superimposed on it a sharp absorption. The hydrogen lines are thus doubly reversed and give the appearance of double emission. It is because of this double appearance that we refer to them as the components of the emission lines.

In making a study of the relative intensity of the emission components of the hydrogen lines in the spectra of B type stars, it is necessary to obtain a standard calibration or reduction curve by means of which all results may be reduced to a common standard. Many methods have been developed by others to study certain problems.[1] These methods were of no avail in this investigation because of the nature of problem and available equipment. Fundamentally all methods are alike and consist in comparing photographically the stellar spectra with a standard source whose intensity distribution along the spectrum is known or assumed to be known. The photometer may be calibrated in a number of ways,[1] but fundamentally the calibration curve is obtained by means of a set of standard exposures whose intensities vary progressively in a constant ratio.

In this investigation a standardizing photometer for impressing the standard exposures is used. It consists of a light tight box blackened on the inside. At one end is placed a 50 watt 220 volt frosted mazda lamp. At the other end is attached a sensitometer box in which are placed ten tubes, seven inches long and three-eighths of an inch in diameter, adequately diaphragmed to eliminate stray light. At the upper end of each tube, directly below a plate holder slide, is placed a diaphragm one millimeter in diameter. The diaphragms at the lower ends vary progressively in area with the constant ratio of two to three. The smallest area is 1.000 square millimeters, the next 1.500, the next 2.250, and so on to the last which is 38.444 square millimeters. The areas cover a range of intensities of nearly four stellar magnitudes. Between the lamp and sensitometer box there are screens of opal glass to diffuse the light or to filter the light by means of appropriate color filters.

The plate of standard exposures contains twenty sets of ten images corresponding to twenty different exposure times ranging from eleven to seventy seconds. From these two hundred exposures a calibration curve for the spectrophotometer was determined as follows:

The galvanometer deflection for each image is obtained corresponding to five distinct constant deflections between opaque (infinite density) and clear film. In other words for each image five readings are obtained corresponding to five distinct clear film readings. Measuring these deflections from opaque as reference and plotting image deflections against clear film deflections, we obtain a straight line for each image. To check this linear relation, four continuous records were made of a Hartmann photometer wedge corresponding to four different clear film deflections. These curves, when reduced linearly to one clear film deflection, gave four identical curves. Consequently the relation between deflections for the standard exposures and clear film is linear.

Because of this linear relation it was decided to reduce all image deflections to eight centimeters clear film deflection. This is accomplished by simply reading the image deflection for each of the two hundred images from the straight lines at eight centimeters clear film deflection. By plotting these deflections of the standard exposures against the logarithm of the respective areas, we will obtain twenty curves corresponding to the different exposure times. These curves were shifted laterally to form one curve, which is called the standard calibration curve.

The fact that we can combine these curves corresponding to different exposure times into a single one shows that in the range of exposure times used the exposure time is independent of the form of the reduction curve. Various exposure times simply give us different portions of the final reduction curve. Furthermore, it is obvious that the final reduction curve is better determined than any single one, and that it covers well the entire range from practically opaque to clear film deflection.

In Plate I, A gives the curves connection image deflection with

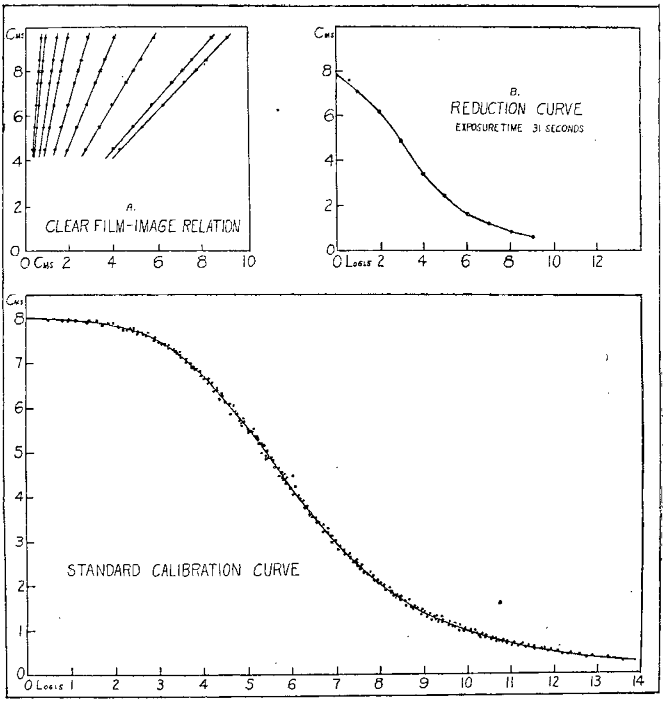

PLATE I

clear film deflection corresponding to thirty-one seconds of exposure time. The crosses indicate the image deflection corresponding to eight centimeters clear film deflection. The corresponding curve of image deflection against logarithm of aperture areas is shown at B. The standard calibration curve is shown at C. The vertical scale is in centimeters and the horizontal scale is given in units of the logarithm of one and one-half to the base ten.

To save time in the reduction and to gain in accuracy a direct reading table was formed corresponding to the standard calibration curve.

To photograph the intensity distribution of spectral lines and of continuous spectrum, a spectrum plate is placed in the plate carrier of the spectrophotometer, the analysing beam is carefully focussed on the spectrum which in turn is focussed on the thermopile. The current in the analysing lamp is adjusted to give the approximate eight centimeter deflection for clear film. While the spectrum plate is moving across the analysing beam the galvanometer deflections are photographed on photoraphic paper placed on a revolving drum. Clear film and opaque reference marks are also photographed. Such records are called photograms.

In Plate II are shown two typical two prism photograms of Phi

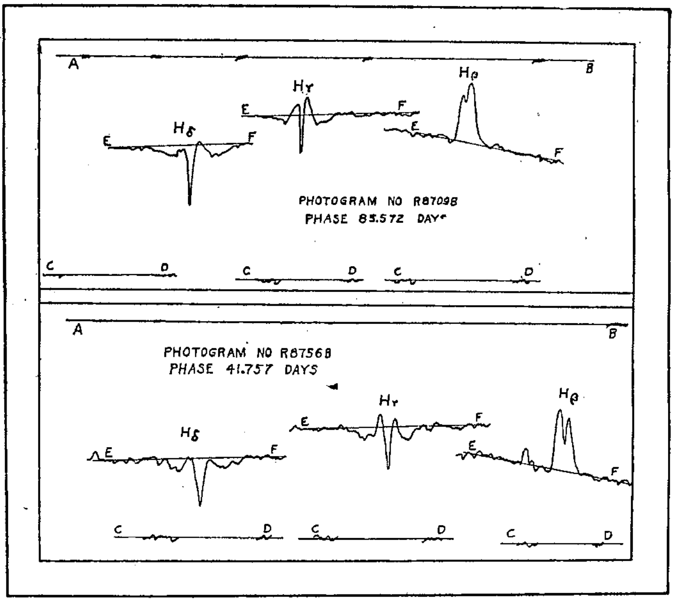

PLATE II

Persei. The upper one is that of plate R8709B at phase 85.572 days where the red component is more intense than the violet, and the lower one is that of plate R8756B at phase 41.757 days where the violet component is more intense than the red. In both records the wave length increases toward the right.

In measuring the photograms, straight lines were drawn through the opaque reference marks as AB, and through the clear film reference marks for each spectral line as CD on Plate II. The imaginary continuous spectrum at each line was drawn in by a line EF, which joined the mean of the continuous spectrum on either side of the spectral line. The deflection from opaque to clear film, to densest point of emission, to continuous spectrum at center of line, and to least dense point of absorption were measured with a standard millimeter scale.

These measures were reduced linearly to the standard clear film deflection of eight centimeters. Then the differences of violet emission minus red emission, central absorption minus continuous spectrum at center of line, and continuous spectrum at hydrogen delta minus continuous spectrum at hydrogen beta were changed into intensity ratios, expressed as the difference of the logarithms of the actual intensities, by means of the standard calibration table at the mean of galvanometer deflection.

By forming mean places and plotting against phase expressed in days the variation is represented graphically in Plates III and

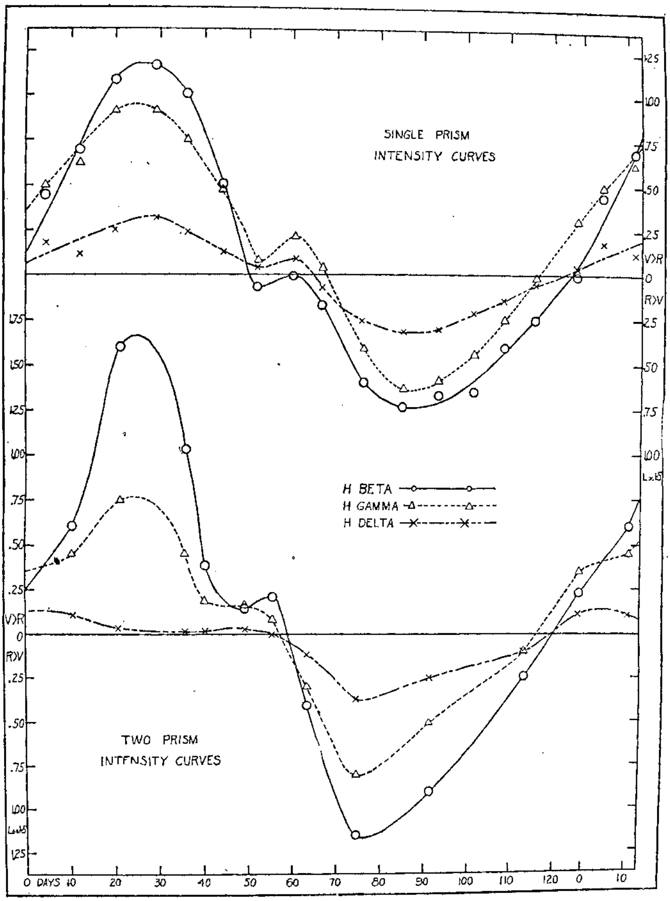

PLATE III

IV. The period used in computing the phases and the epoch to which they refer are those given by Doctor Dustheimer,[2] namely a period of 126.626 days and zero phase at the instant of November 18.000, 1925 greenwich mean time.

In Plate III are shown the relative intensity variations of the emission components of hydrogen beta, gamma and delta for single and two prism spectrograms made at the Detroit Observatory. These curves not only show a regular variation in the relative intensity of the emission in a cycle of 126.626 days but also a pronounced secondary variation near equal relative intensity on the descending branch between phases 40 to 60 days. In addition several other variations may be pointed out to exist between the lines for the single or two prism plates, that is a variation from line to line as well as variations in the same line during different cycles.

In plate IV are shown the intensity variations of the central absorption of delta and gamma of hydrogen relative to the con-

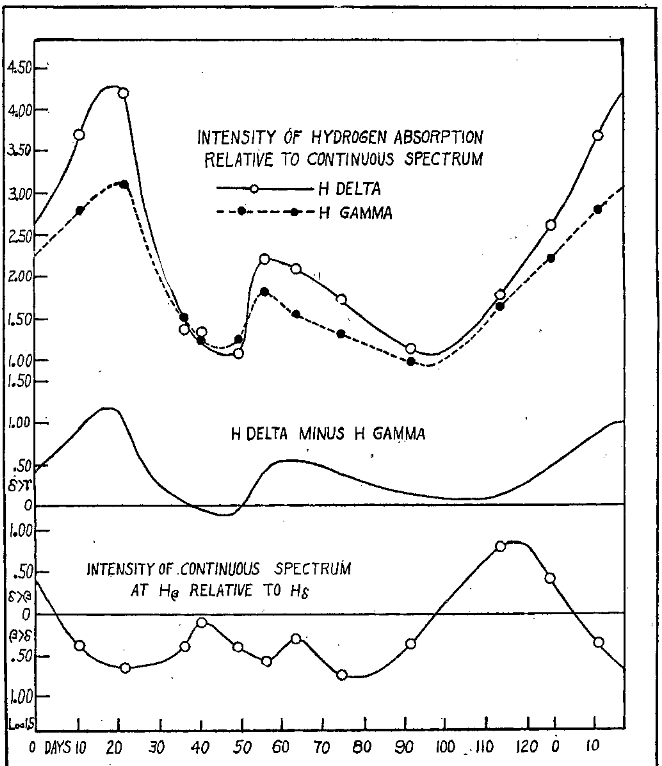

PLATE IV

tinuous spectrum at these lines. At the bottom is shown the variation of intensity of the continuous spectrum at hydrogen beta relative to that at hydrogen delta. Here again we note a regular variation with a more pronounced secondary variation and a lead in phase at maximum for the hydrogen absorption.

From the foregoing discussion it is clearly seen that the hydrogen emission and absorption lines and the continuous spectrum of the star Phi Persei undergo great intensity changes. These can be studied to great advantage by means of the Moll self-registering microphotometer. Similarly, it is possible to study the changes which occur in the emission width directly from the photograms.

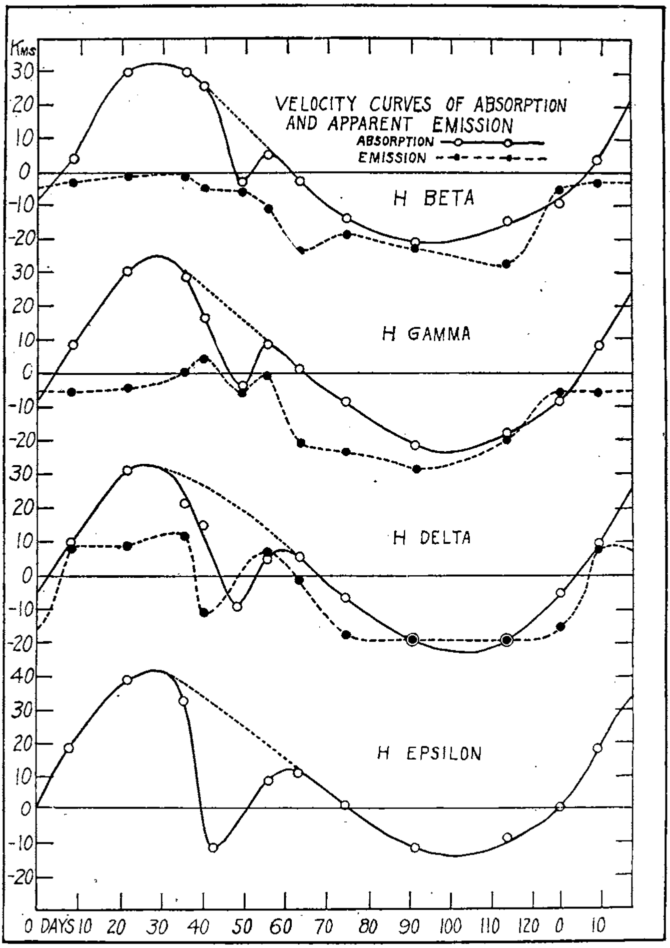

PLATE VI

However, the accuracy, which is obtainable, is inferior to that obtained by direct measurement. Since the discussion of variability of hydrogen lines in Phi Persei would not be complete without studies in width of lines and components, and also of velocity determination, the writer has measured all the two prism plates to bring out these variations.

The method of measurement, computation of dispersion curve and reduction of measurements to radial velocity or line widths is discussed elsewhere.[3] It suffices to mention that the displacement of a spectral line relative to a laboratory comparison spectrum is interpreted according to the Dopple principle as due to radial motion of the source, since the motion of the earth is allowed for in the reduction. The spectroscopic results are given graphically in Plates V, VI, VII and IX.

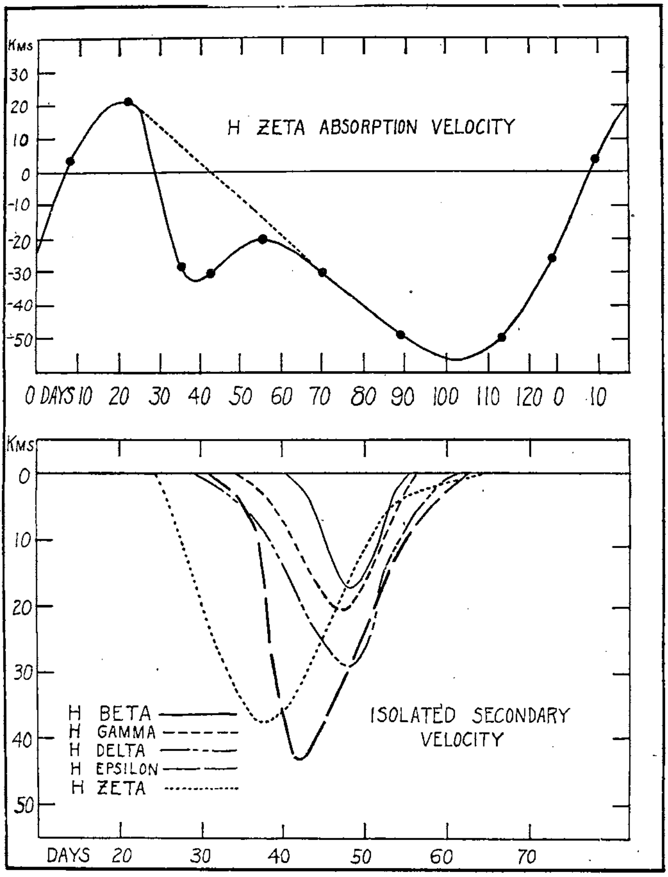

PLATE VII

In Plate VI are given the velocity curves for the absorption and emission of hydrogen beta, gamma, delta and epsilon. In addition to the similar regular variation of the absorption velocity there is a variable secondary velocity variation near zero velocity on the descending branch. The curve for epsilon of hydrogen shows an additional redward displacement due to a blend with H of calcium on the violet. The secondary variation may be isolated by drawing a mean curve in such a way to have all of the secondary variation below the mean curve.

In Plate VII we have the absorption velocity for zeta of hydrogen at the top. Besides the regular and variable secondary variation there is an additional violet displacement due to a blend with a helium line on the violet and an excess violet displacement at minimum due to maximum intensity of helium and minimum intensity of hydrogen. At the bottom of Plate VII the secondary velocity variation of hydrogen absorption is isolated. It is seen that the secondary variation appears first, is more violent and persists longer in lines of shorter wave lengths. If we accept the modern view, that the spectral lines are produced at different effective atmospheric levels, then this secondary variation is caused by something which affects lower levels more than higher levels. This then may lead to an explanation regarding the puzzling features which are observed in this star.

From the above consideration of the various variations in velocity curves for the different spectral lines, it is clear that we must examine the velocity curves critically for each line before we combine them into one mean curve. By the habitual formation of a mean curve we surely mask many curious features which would lead to entirely different conclusions.

In Plate IX are shown the velocity variations for the violet and red emission edges of hydrogen beta, gamma and delta. It is seen that the variations, although quite irregular and complicated, are consistent for the three lines. They show one important feature and that is that at times the two edges show opposite displacements and at times they show similar displacements. Consequently, an emission velocity curve for this star, formed by taking the mean of the settings on the edges has little meaning. Such a curve can be interpreted readily only when the two edges show identical curves. Since only part of the displacements of the emission edges can be attributed to radial motion, the remaining must be due to an actual widening of the line itself.

In Plate V are shown the curves for the variation in width of

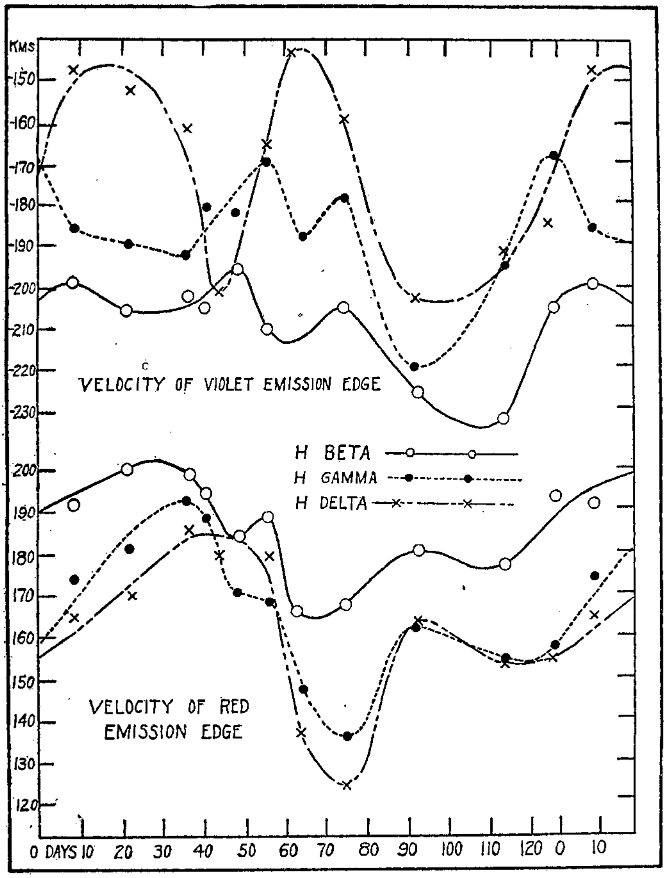

PLATE IX

total emission, and for the red and violet emission components for hydrogen beta, gamma and delta. These curves clearly show that the total widths of emission are greater for lines of longer wave lengths,[4] that the variation in width is greater for lines of shorter wave lengths, that during one period each curve shows two maxima and two minima,[2] that there is a pronounced variable secondary variation, and a definite lag in phase for lines of shorter wave lengths.

Many features are found parallel in the intensity curves to those of line widths. The two results are obtained by independent methods, which establishes them as real beyond a doubt. By carefully considering the various factors which may contribute towards changes in widths, intensity and radial velocity we may make some

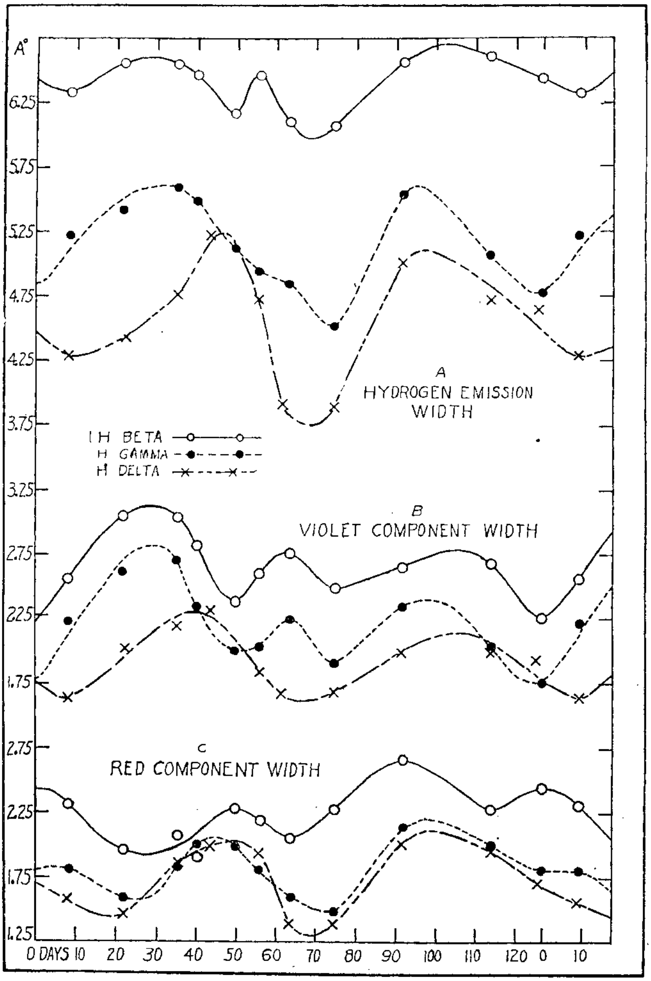

PLATE V

progress toward the solution of this complex problem. Three hypotheses will be considered for the explanation of the observed features.

The first possible interpretation is that of orbital motion of two stars each contributing to hydrogen emission and absorption. We would have to assume further, that the hydrogen central absorption is produced mainly in one star and that this star also contributes the greater portion to emission. If we assume further that the shifting of absorption and emission from one star relative to the other produces marked photographic effects [5] which are more pronounced for lines of weaker emission, namely of shorter wave lengths, then such a system can account for many of the observed spectral features. However, for others it can account only partially or not at all. Let us therefore consider the second hypothesis.

The second hypothesis assumes a star of very extensive atmosphere, which is pulsating with a main pulsation to account for the main velocity variation and with a secondary variable pulsation to account for the secondary velocity variation.[6] Atmospheric pulsation would not only produce radial velocity variation, but also variation in pressure, temperature, ionization and indirectly in Stark effect giving rise to intensity and line width variations as well as producing a photographic effect as in the first hypothesis.

The secondary velocity variation in absorption, which is observed just after maximum rate of contraction, finds an explanation in the assumption that upon rapid contraction much of the radiant energy becomes imprisoned. This wholesale imprisoning of radiant energy will create momentarily so great a pressure that a violent outward motion results. Rapid dissipation of this outward motion is inevitable and consequently the effect on outer layers is observed later, is less pronounced and first to disappear. Assuming then that lines of longer wave lengths are produced in an effective higher level gives an adequate explanation for the secondary variation as observed in the hydrogen absorption velocity.

Pulsation is indeed a promising theory to explain the observed features of Phi Persei. However, such an explanation would require changes in the radius of the star which are greater than the radii of normal B type stars and it may be inconsistent with the absence of measured light variation.

To partly overcome the difficulties encountered in the pulsation theory a third hypothesis is proposed. This assumes a star of very low density, pear-shaped or apioidal in form, of very extensive atmosphere, small and ill-defined photosphere, which is rotating and pulsating with the period of velocity variation. It assumes that the effective photosphere is eccentric with reference to the axis of rotation, and that the central absorption is produced in the atmosphere between the observer and photosphere while the emission is produced in the projecting atmosphere.[7] Assuming expansion during approach and contraction during recession of the effective photosphere the observed features are explained more satisfactorily by this hypothesis that by the others. However, it must encounter the objection that on such a basis variations in the total light of Phi Persei would be expected but have not been observed.

Finally, I wish to express my indebtedness to the late Prof. Ralph H. Curtiss of the Detroit Observatory for his kindly criticism, suggestions and direction; to Prof. H. M. Randall of the Physics department of the University of Michigan for the use of the Moll Spectrophotometer.

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